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SDC SOLENOID DESIGN NOTE #180

TITLE: DESIGN STUDY OF A THIN SUPERCONDUCTING SOLENOID MAGNET FOR THE SDC DETECTOR

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DESIGN STUDY OF A THIN SUPERCONDUCTING SOLENOID MAGNET FOR THE SDC DETECTOR

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Abstract-A thin superconducting solenoid magnet has been designed for the SDC detector; one of major colliding particle detectors for the SSC high energy particle accelerator project. Based on recent R&D efforts to develop high strength aluminum stabilized superconductor and honeycomb/isogrid vacuum shell, the thin solenoid has been designed to provide a central magnetic field of 2 T in a tracking volume of 3. 4 mϕ x 8.8 m, with a magnet wall transparency of 1.2 Xo. This report describes the conceptual design and progress of the R&D work.

I. INTRODUCTION

The SDC solenoid is designed to provide an axial magnetic field of 2 T over the charged particle tracking volume of 3.6 mϕ x 8.8 m in the SDC detector, which is one of major colliding particle detector to be built in the SSC accelerator [1-3]. Figure 1 shows an artist's impression of the 40 meter-long SDC detector, which will measure trajectories and energies of particles emerging from the 40 TeV center-of mass collisions. The superconducting solenoid magnet is surrounded by electromagnetic and hadronic calorimeters used to measure the energy and impact points of the particles. The magnetic flux return of the magnet is provided by the iron absorber plates of the hadron calorimeters (HAC) as shown in Fig. 2.

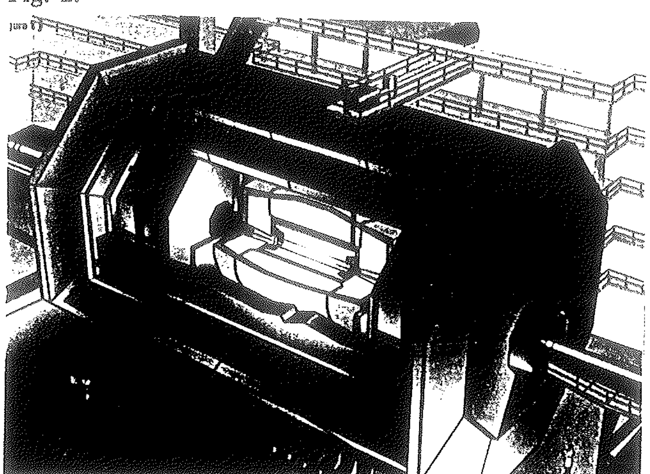

Fig. 1. Artist's impression of the SDC detector.

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Since all wide angle particles must pass through the superconducting coil and cryostat before impacting the calorimeter, the desired calorimeter performance requires the material in the coil to be minimized both in terms of radiation lengths (Xo) and absorption length (λo). Based on recent technical advances in aluminum stabilized superconductor and thin wall vacuum-shell using honeycomb or isogrid techniques, the SDC solenoid is designed to provide a magnetic field of 2 T with a transparency of 1.2 Xo or 0.25 λ_I at $\eta = 0$ (90 degree from the beam axis.).

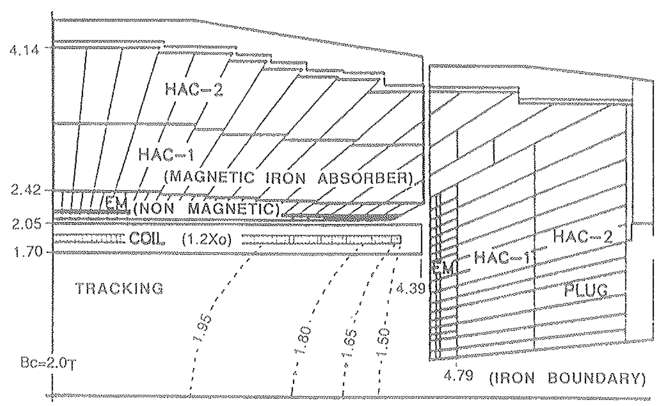

Fig. 2. A quadrant cross section of the solenoid magnet surrounded by electromagnetic calorimeter(EM non magnetic) and hadron calorimeter (HAC) with iron absorber.

II. MAGNET DESIGN

A. General Design

Field uniformity and coil forces are strongly influenced by the proximity of the ferromagnetic iron absorber in the hadron calorimeter and are very important in both of physics and magnetic design. These effects were evaluated in a series of axisymmetric finite element analyses using the ANSYS finite element program[4]. Figure 3 shows the coil compressive force and the axial decentering force as a function of the endwall position. In the present SDC detector design, the axial end wall of the ferromagnetic absorber is located at about 60 cm from the coil end. Therefore, the magnet design must allow an axial compressive force of 1300 tonnes and an axial decentering force of 40 tonnes in addition to the general

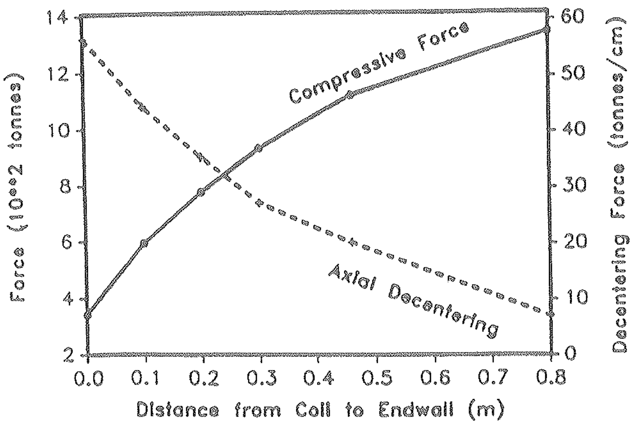

Fig. 3. Coil compressive force and axial decentering force as a function of the axial distance between the end of the coil and the iron endcap calorimeter (HAC).

requirements. Table 1 summarizes a baseline design parameter of the SDC solenoid and Tab. 2 gives a breakdown of the contributions to the transparency under the cross sectional configuration of the magnet as shown in Fig. 4.

B. Boundary conditions for Magnet Safety Design

In order to optimize safety and reliability condition as well as thinness of the magnet, the following safety guidelines have been incorporated into the baseline coil design

- To homogenize the stresses in the coil outer-support-cylinder cold mass, the mechanical design will limit the strain in the outer support cylinder to 0.1 %; ~~an averaged stress level of 70 MPa in aluminum.~~
- To eliminate unacceptable thermal stress in the cold mass following a quench, the maximum hot spot temperature will be limited to 100 K.

Table 1. Baseline Design Parameters of SDC solenoid

Dimensions:		
Cryostat	Inner radius	1.70 m
	Outer radius	2.05 m
	Half length	4.39 m
Coil	Effective radius	1.84 m
	Half length	4.15 m
Transparency (Radiation length)		1.2 Xo
Electrical:		
Central field		2 T
Nominal current		8,000 A
Inductance		4.6 H
Stored Energy		146 MJ
Stored energy /cold mass		7.4
kJ/kg		
Mechanical:		
Effective cold mass		20 tonnes
Total weight		25 tonnes
Radial magnetic pressure		1.6 MPa
Axial compressive force		13 MN
Axial decentering force (at ΔZ=2.5 cm)		0.4 MN

Table 2. Transparency of SDC solenoid wall.

Element	Eff. Thickness [mm]	Xo	λ_I
Superconducting coil:			
Outer sup. cylinder	31.0	0.348	0.0787
Superconductor			
Al stabilizer	39.0	0.438	0.0990
Nb.Ti/Cu	2.9	0.181	0.0167
GFRP	3.1	0.016	0.0058
Al strips	2.0	0.022	0.0051
Cryostat:			
Outer vac. wall	7.1	0.08	0.0180
Outer rad. shield	2.0	0.022	0.0051
Inner rad. shield	2.0	0.022	0.0051
Inner vac. wall	6.0	0.067	0.0152
Super-insulation	2.0	0.007	0.0023
Total		1.20	0.251

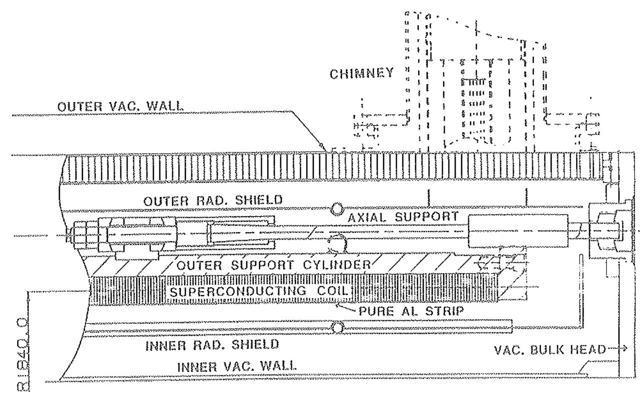

Fig. 4. Cross section of the end portion of the SDC solenoid

C. Technical Efforts for a Thinner Solenoid

A useful parameter to gauge the relative transparency (or thinness) of superconducting coils is the ratio of stored magnetic energy to cold mass (E/M) . The E/M ratio in the oil determines the average coil temperature rise after a quench. If we assume uniform dissipation of all of the coil's stored magnetic energy in the coil after a quench, the E/M ratio should be approximately equal to the coil enthalpy at the coil temperature after the quench,

$$E/M = H(T2) - H(T1) = \text{approx. } H(T2)$$

where H is the coil enthalpy, T2 is the average coil temperature after the quench, and T1 is the coil initial temperature. In solenoid presently in use at various high energy physics laboratories, the E/M ratio is around 5 kJ/kg, as shown in Fig. 5.[5-11] This corresponds to an average coil temperature rise of 65 K after a quench according to the above relation. If the quench propagation speed is very fast and results in a homogeneous energy dump into the coil, we may still allow further temperature rise before facing to thermal

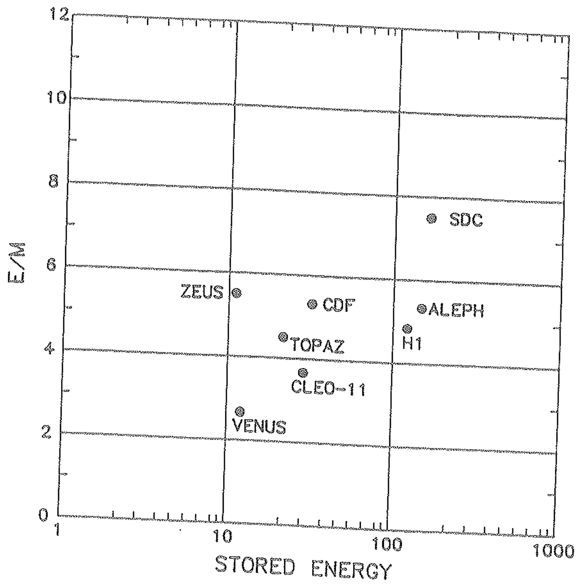

Fig. 5. Ratio of stored energy to cold mass [E/M) for various detector thin solenoids.

stress problem beyond 80 K. It means we may assume an E/M ratio of 8kJ/kg, corresponding to T2 = 80 K. Including a contingency, a design goal of 7.5 KJ/kg has been decided upon for E/M in the SDC solenoid. It is a major concept to save a radiation thickness of 0.4 in the coil and to result in a total radiation thickness of 1.0 Xo in the coil part with keeping operational safety condition mentioned above.

In order to operate the magnet under such a high E/M condition, mechanical improvement of Al stabilizer is very important and effective. If a stress level of 60 MPa was allowable in the Al stabilizer instead of a present stress limit level of 20 - 30 MPa in the existing 4N-5N Al stabilized thin solenoid coils, the SDC solenoid may be operated within elastic boundary condition and the overall stress, the coil deformation may be minimized as shown in Fig. 6.

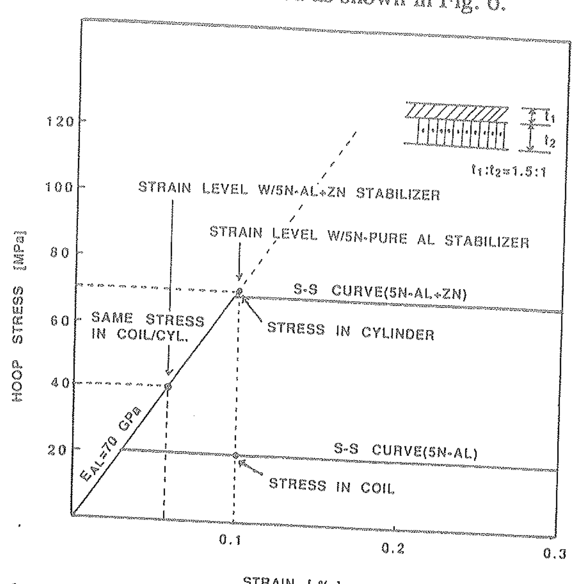

Fig. 6. Stress strain level comparison between 5N-pure Al and high strength Al in combination with outer support cylinder.

In the base line design, the goal for the yield strength of the pure aluminum stabilizer has been set to be > 65 MPa.

Fast quench propagation is also important to keep the coil temperature uniform and peak temperature lower enough. Recently, a technical concept to enhance transverse quench propagation velocity by using pure aluminum strips has been developed in a thin solenoid development [12-14] and this technique is to be applied in the SDC solenoid as described later.

An effort to reduce the effective thickness of the vacuum vessel has also been considered. Either honeycomb or isogrid for the outer vacuum wall would be very effective for this purpose. Based on recent R&D on isogrid and brazed honeycomb structure, either one could save about 0.2 Xo relative to solid aluminum. Taking these effects into account, we may expect a radiation thickness of the outer vacuum shell to be reduced down to 0.1 Xo.

D. Coil Design

The solenoid coil consists of a single layer-coil and an outer support cylinder as shown in Fig. 4. The coil is directly wound inside an outer support cylinder made of 5083-H32 aluminum alloy. Using the E/M ratio of 7.5 kJ/kg, a total cold mass thickness of 75 mm has been determined by:

$$t = E / \{(2 \pi R t l \rho) \times (E/M)\}$$
$$= 0.075 \text{ m}$$

Here R, t, l and r are the coil radius, total thickness including the support cylinder, coil length and the density of aluminum, respectively. The sharing of this total radial thickness between the superconductor and the support cylinder has been determined with two criteria: quench stability and safety, and conductor fabrication. A superconductor thickness of 44 mm has been determined to keep the coil temperature less than 100 K after a quench, even if the total stored energy were dumped entirely into the conductor in case of switch failure. The outer support cylinder therefore becomes 31 mm thick. The electrical ground insulation between the coil and support cylinder consists of two glass- epoxy layers applied before the coil winding and the thickness to be 0.2 mm. against a breakdown voltage of > 2 kV.

A helium cooling pipe with an inner diameter of 25 mm is welded to that outer surface of the support cylinder. The single serpentine path has 28 axial passes and total cooling path length of 250 m in the coil part.

The mechanical design in the solenoid must be very reliable especially in the following stresses;

1. The combined hoop and axial stress, or stress intensity, in the superconductor during magnet operation. This generates a maximum shear stress ($2\tau = s_1 - s_2$) in the pure aluminum at the axial coil center, h z
2. The shear stress at the boundary between the coil and the outer support cylinder due to the axial electro---- magnetic force, which is a maximum at the coil end.

A finite element analysis has been carried out to calculate this stress precisely. Figure 7 shows stress components in the superconducting coil part. The maximum stress intensity in the conductor is 52 (=40 + 12) MPa and the shear stress at the epoxy bond boundary between the coil and outer support cylinder is less than 1 MPa. Figure 8 shows the coil deformation due to these stresses. The strain level is less than 0.1 % as desired.

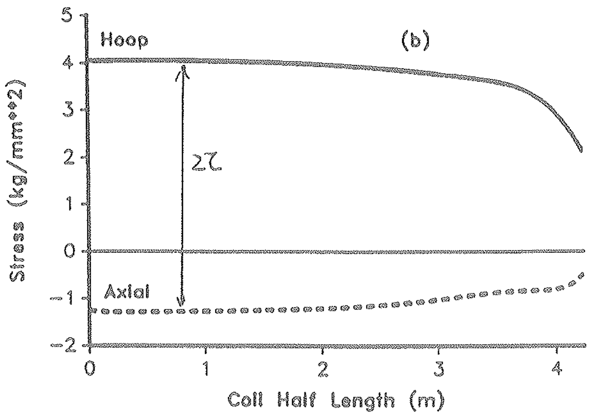

Fig. 7. Stress level in the coil during excitation.

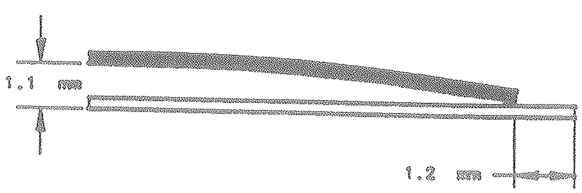

Fig. 8. Coil deformation due to electromagnetic force.

In order to satisfy the design guideline of a maximum temperature less than 100 K after a quench-even without a dump resistor--(e.g., in case of some failure of a protection circuit), the stored energy must be dumped as uniformly as possible into the coil. This can be realized if the quench propagation time constant is much faster than the power decay time constant during the quench. A quench propagation technique by using pure aluminum strips is to be used in the SDC solenoid. The pure aluminum strip pasted inside the coil surface serves to enhance the effective thermal conductance in the axial direction by bypassing the axial electrical insulation and to enhance the axial quench velocity v(z) according to the following relation[15]:

$$v(z) = \{k_z / k_\phi\}^{1/2} = \varepsilon^{1/2}$$

where k_z and k_ϕ are axial and circumferential thermal conductances in the coil. In the SDC solenoid, axial pure aluminum strips with a thickness of 2 mm is planned to be pasted inside the coil surface to keep the maximum coil temperature of 100 K or less after a quench. Figure 8 shows results of a computation of the temperature rise after a quench

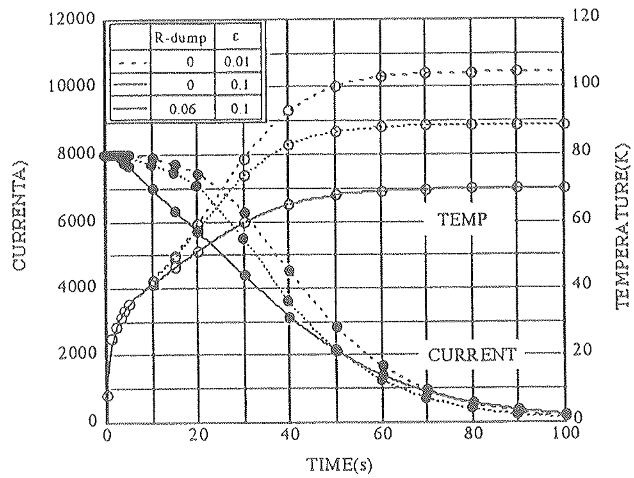

Fig. 9. Quench simulation by using the code"QUENCH".

by using the computer code "QUENCH" [15]. In theses calculations, it was assumed that half of mass in the support cylinder may contribute to absorb a stored energy in the coil. RRR of aluminum stabilizer was assumed to be 200 including magneto-resistance effect at 2 T.

In normal switching operation with R-dump = 0.06 Ω, after a quench, the maximum temperature was calculated to be 70 K. Even in a case of the switch failure, the maximum temperature was calculated to be 90 K. Assuming pure aluminum strip functioned as desired (ε > 0.1). .In the last case of switch failure (R-dump = 0 Ω) and no pure aluminum strips (ε < 0.01), the maximum temperature become more than 110 K.

E. Superconductor Design

Design parameters of aluminum stabilized superconductor has been optimized based on the previous design study. An operational current of 8,000 A was chosen as a result of the optimization in conductor size (radial thickness of 44 mm) and the area aspect ratio. A superconductor cable is co-extruded in the center of the aluminum stabilizer. The cable, consisting of ten compacted strands, enables us to make cable unit-lengths between joints much longer than that of the monolithic strands and also provides its higher critical current density because of its smaller filament size. The 8,000 A operating point will be 50 % along the load line to the conductor capability at 4.2 K. The operating point corresponds to a critical temperature of 6.7 K and, therefore, the temperature margin is 2.5 K. The maximum field of 2.8 T is expected with a self field enhancement of 0.5 T at the coil end at 8,000 A. Based on recent experimental studies, the purity of the aluminum stabilizer has been optimized at a purity of 99.999 % with 200 ppm Zn added. This improves the mechanical strength with little degradation of the residual resistivity ratio (RRR) as described later. A yield strength of >67 MPa is expected with RRR = 500 at B=0 T and RRR=200 at B= 2T in the SDC solenoid operation

For assuming present conductor design, the minimum quench energy (MQE) in the SDC solenoid is estimated to be 0.3 J by using a simple one-dimensional model [15] Design parameter of the conductor are summarized in Tab. 3.

Table 3. Design parameters of the SDC superconductor.

Configuration of superconductor:		
Superconductor material		NbTi/Cu
Stabilizer	(base material)	Al (99.999%-up)
	(additive)	Zn(200 ppm)
Area ratio	(NbTi/Cu/Al)	1 / 1 / 29.8
Overall width (outer/inner)		4.42 / 4.32 mm
Overall radial thickness		43.8 mm
Thickness of conductor insulation		0.1 mm
Superconductor strand:		
Strand diameter		1.277 mm
NbTi filament diameter		20 μm
Filament twist pitch		27 mm
Number of filaments		4100
Superconductor cable:		
Overall size		6.4 x 2.2 mm^2
Number of cables		10 (2x5)
Cabling pitch		50-60 mm
Jc in NbTi	(@ 5 T, 4.2 K)	2500 A/mm2
Critical current (@ 5 T, 4.2 K)		16,000 A
Operation current (@2.8T_{max}, 4.2 K)		8,000 A
Characteristics of Al stabilizer:		
RRR	(@B=0)	500
	(@B=1 T)	200
Yield strength of Al	(@4.2 K)	>67 MPa
Shear strength (Cu/Al boundary)		>20 MPa

III. CRYOSTAT DESIGN

A. Radiation Shield

Two cylindrical radiation shields are place inside and outside the coil, between the coil and the vacuum walls. The shields are made of A5083-H32 with a thickness of 2 mm. These two cylinders are jointed by end flanges to become one coaxial unit which is supported from the vacuum bulk heads through axial GFRP rods. The shield is broken electrically in the circumferential direction to eliminate the force due to eddy currents induced by a fast discharge of the magnet. The path of the 15 mm inner diameter cooling pipe on the shield is similar to that on the outer support cylinder. It has 16 serpentine passes in series with a total pipe length of 320 m.

B. Cryostat Vacuum Vessel.

The vacuum vessel for the SDC solenoid consists of inner and outer coaxial shells with flat annular bulkheads on the axial ends. The cold mass is suspended inside the vacuum vessel by the support system. The superconducting leads and the cryogen pipes leave the vacuum vessel through a chimney at one end of the outer shell. Since an external pressure of 1 atm is loaded on the outer vacuum shell, it is very efficient to use "honeycomb" or "isogrid" panel technique in order to enhance stiffness of the plate with saving material. Table 5 summarizes a technical comparison especially for effectiveness of "honeycomb" and "isogrid" plates with solid plate.

Table 4. Comparison of solid, isogrid and honeycomb outer vacuum shells.

	Solid	Isogrid	Honeycomb
Aluminum alloy	5083	5083-H32	6951/ 4045-T6
Total thickness [mm]	27	46	46
Skin thickness [mm]	---	4.0	3.0+3.0
Effect. thick. [mm]	27	11	7
Weight reduct. ratio [mm]	1	0.4	0.26
Radiation thick. [Xo]	0.303	0.123	0.079
Units to be assembled	12	12	21

Technical selection to use "honeycomb" or "isogrid" will be made based on results of R&D programs.

C. Coil Support

The purpose of the support system is to transmit both the cold mass and electromagnetic decentering loads from the 4.2 K coil package to the vacuum bulkhead at 300 K.
For the purpose of designing the support system, it is assumed that the load of 40 tonnes in addition to the downward coil self-weight of 20 tonnes. The support system must have a spring constant greater than the decentering force constant in order to be stable and to keep the defections small. As a design guide line, a factor of 5 is assumed in the present design.

A dedicated type of support system chosen consists of axial members to provide longitudinal stiffness and approximately tangential member to provide radial stiffness as shown in Fig. 10. The member connect between the outer support cylinder and the flat annular bulkhead of the vacuum vessel. A set of 14 axial compression-tension members is located on the chimney end of the cryostat only while the tangential tension members are located at both ends. Both types of members are fabricated of uni-axial epoxy-fiberglass (GFRP) composite and have a design safety factor of 4 against the GFRP ultimate strength of 700 MPa at least. The axial members are also designed for buckling safety factor of 4. The GFRP members have thermal intercepts which operate near 80 K and at 4.5 K.

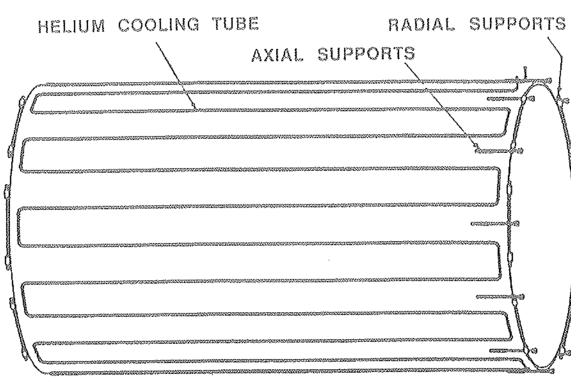

Fig. 10. The SDC coil and support configuration.

D. Chimney

A chimney of 30 cm in diameter and 10 m in length runs vertically upward though the detector at an axial end and on the top of the solenoid magnet. In the chimney, cryogen lines and superconducting leads from the solenoid coil extend through the detector to the service port on the top of the muon detector.

IV. CRYOGENIC DESIGN

The superconducting coil is cooled by the forced flow of two phase helium inside a single pass cooling tube on the outer support cylinder. The CDF and TOPAZ thin solenoids are cooled in this manner [6,7]. Their operating performance has demonstrated that indirect cooling is effective and reliable. This method was chosen because it is simple and requires less radial space in the cryostat. The thermal radiation shield will be cooled with either gaseous helium from an intermediate stage in the refrigerator or with force flow liquid nitrogen. Estimates of the normal operating, steady state heat loads including a contingency of 20 %, are given in Tab. 5. Cooling design parameters for the SDC solenoid coil are given in Tab. 6.

The SDC solenoid cryogenic system consists of a helium refrigerator/liquefier, liquid and gas transfer lines, liquid and gas storage, and a control dewar. General requirements for the SDC cryogenic system based on SDC solenoid design are summarized in Tab. 7. Schematic diagram of the cryogenic system is shown in Fig. 11.

V. ELECTRICAL SYSTEM

The electrical system to energize the solenoid magnet consists of a DC power supply, fast and slow discharge resistors and high current DC switches. A nominal operational current of 8,000 A is required with a voltage capacity of 30 V to allow an inductive (L/Di/dt) voltage of +/-17 V and a resistive voltage drop of 10 V in bus-bars from the surface tot the detector hall with a length of about 200 m. Two discharge mode will be required.; one for fast discharge after a quench and another for slow discharge to eliminate an induced quench.

Table 5. Estimate of steady state thermal loads.

Temperature [K]	300-77	77-4.2	300-4.2
Thermal radiation:	300	30	---
Thermal conduction:			
Coil support	24	2.5	---
Shield support	3	---	---
Chimn. & Service port	36	4.5	
Current leads (8,000 A)			30 (L/h)
Miscellaneous	37	3	
Total thermal load	400 W	40 W	30 L/h

Table 6. Cooling design parameters.

Cool-down:	
Initial cooling speed	1 K/hr
Temperature difference in coil	< 50 K
GHe mass flow (ΔT=50 K)	21 g/s
Steady State Operation:	
Typical coil temperature	4.5 K
2ϕ-He mass flow in coil	7 g/s
He mass flow in current leads	1 g/s
Quality (X) of 2ϕ-helium (inlet)	0.2
(outlet)	0.5
Coil Excitation (@ 1mT/s):	
Eddy current loss in support cylinder	90 W
Additional 2ϕ-He mass flow in coil	23 g/s
Quench Recovery:	
Assumed energy dump in coil	90 MJ
Recovery time assumed	4 hr
LHe mass flow required (@ effic.=0.8)	28 g/s (830 L/hr)

Table. 7. General requirements on the cryogenics

Refrigeration capacity at 4.5 K	:	1000 W
Liquefaction capacity	:	300 L/h
2ϕ-He mass flow	:	30g /s
LHe storage capacity	:	5,000 L
Cold GHe (60 K)mass flow capacity rate:		15 g/s

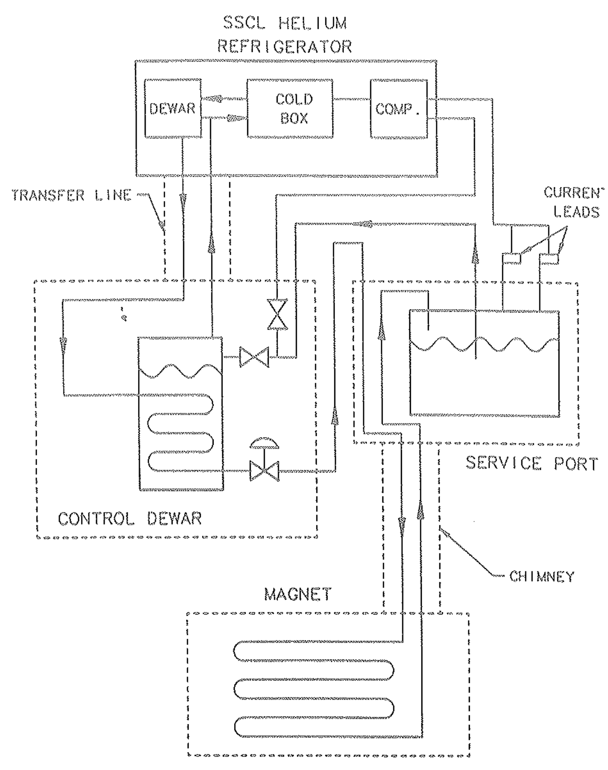

Fig. 11 Flow schematic of the cryogenic system.

VI. PROTOTYPE R&D

A. Prototype magnet

The development of a full diameter, one quarter length prototype magnet has been carried out since 1991. The purpose of the prototype magnet development are:

- to establish the fabrication technique of high strength aluminum stabilized superconductor for a full size coil and to learn coil winding technique.
- to demonstrate that a coil with E/M ratio of >7.5 kJ/kg can be quenched safely; and
- to verify mechanical design under electromagnetic force equivalent to that of the production magnet.

Main parameters of the prototype solenoid are given in Tab 8.

Table 8. Main parameters of the prototype solenoid.

Dimensions			
	Cryostat	Inner radius	1.70 m
		Outer radius	2.06 m
		Half length	1.17 m
	Coil	Mean radius	1.84 m
		Half length	0.95 m
Electrical:			
	Central field (max) in air		1.5 T
	Peak field		3.8 T
	Current (max.)		11,250A
	Inductance		0.68 H
	Stored energy (max)		48 MJ
	Load line ratio		70 %
Mechanical:			
	Radial magnetic pressure		1.7 MPa
	Axial compressive force		17 MN
	Coil weight		4.5 tonnes
	Total weight of the magnet		8 tonnes

B. Conductor Development

An extensive R&D effort has been made to improve the mechanical strength of the Al stabilized superconductor with optimization of the RRR in the SDC superconductor and the following sequential process has been established [16]:

- Special alloying process with pure-aluminum of 99.999%-up and an additive of Zn (200 ppm),
- Mechanical cold work to give the alloy a strong reduction in a level of 10 %.

The fabrication process and typical properties of the high strength aluminum stabilizer in the SDC R&D conductor are summarized in Tab. 9. As a result of the development, a yield strength of 65 - 70 MPa at 77 K with RRR = 500 has been successfully achieved. Figure 12 shows cross sections of the developed superconductor. The 6 km superconductor for the prototype coil has been fabricated using this technique. Figure 13 shows critical current characteristics measured with the prototype super-conductor.

Table 9. Fabrication process and properties of high strength aluminum stabilizer

Process	YS (300K)	YS (77K)	RRR (300K/4K)
1. Base metal	[MPa]	[MPa]	
5N-Al (based)	23	30	2,500
2. Alloying:			
Zn-200ppm added		31	680
3. Conductor fabrication:			
Extruded w/ NbTi/Cu	23	29	630
Cold worked (12%)	65	82	490
4. Coil winding process:			
Coil cured (130 C)	55	69	530
5. Aged for 6 months	(no change observed)		

Fig. 12. Picture of the SDC superconductor cross sections: before and after cold work at the top and bottom, respectively.

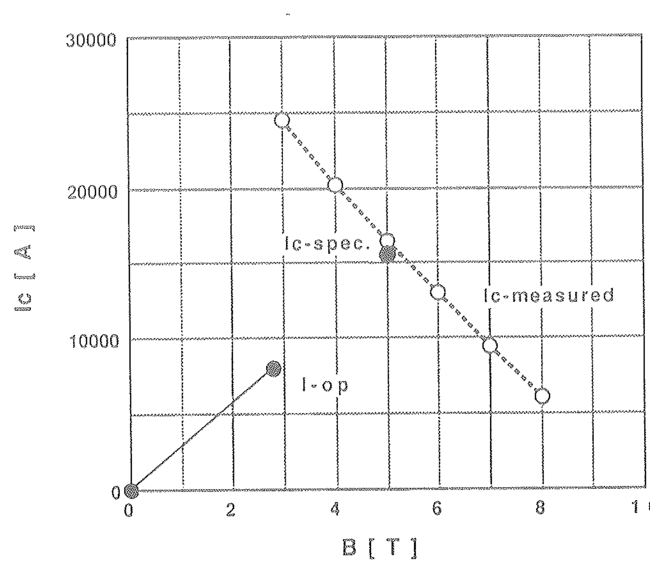

Fig. 13. Measured critical current as a function of the magnetic field in the SDC prototype superconductor..

C. Prototype coil winding

The prototype coil winding is being prepared. Figure 14 shows a bird's-eye-view of a coil winding machine for the prototype. The superconductor pre-wound on the outer surface of a temporal mandrel is installed into inside the outer support cylinder acting as an outer mandrel. The conductor is transferred to inner surface of the outer support cylinder with longitudinal compression along the conductor axis in order to fit the conductor tightly to the inner surface of the outer support cylinder . The ground insulation made of two layer of GFRP thin plate is processed and cured before the coil winding. The conductor insulation made of glass/Kapton (G/K) tape with a thickness of 50 μm is half-over-wrapped around the conductor just before the pre-winding. The G/K tape is epoxidized in B-stage and The wet (A--stage) epoxy-resin is painted, during the inner winding process, on radial outer edge of the conductor in order to eliminate void and to be a lubricant between the coil and the outer support cylinder for smooth winding and axial compression easily to be applied. The coil is cured at 130 degrees in Celsius for about 10 hours under the axial compression and radial internal pressure. Finally pure aluminum strips as a quench propagator are glued on the inner surface of the coil. The prototype coil winding will be started in this fall.

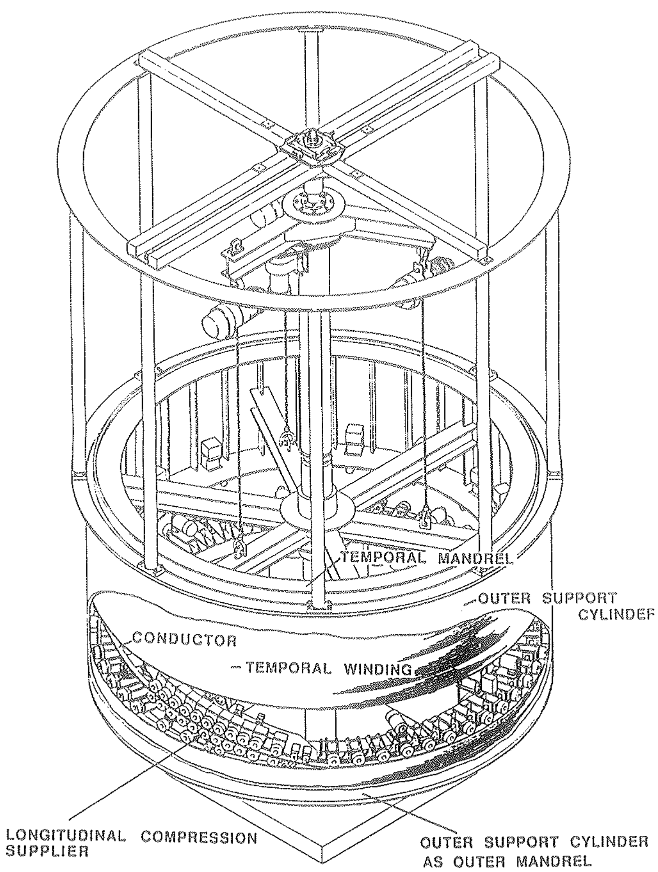

Fig. 13. Bird's eye view of the coil winding machine.

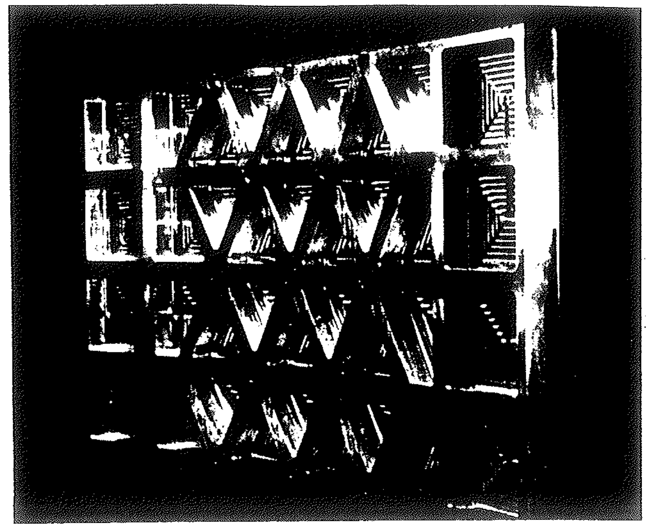

Fig. 14. A picture of Isogrid panel NC-machined for the prototype vacuum shell. R&D.

D. Outer Vacuum Shell R&D

R&D for two techniques of "brazed honeycomb" and "isogrid" are being carried out. The isogrid vacuum shell is to be used for the SDC prototype cryostat to verify its reliability in a large scale [17]. Figure 14 shows a picture of the sample for the isogrid patterns numerically machined from the solid panel. Several pieces of the panels machined and curved with "brake-forming" are assembled to be a cylinder using welding. The prototype cryostat including isogrid outer vacuum shell is planned to be ready in early next year.

Another effort is also carried out to develop a thin vacuum shell by using "brazed honeycomb". A new technical challenge is to form the brazed honeycomb-plates to be cylindrical shape after completion of brazed flat honeycomb panel. It enables us to fabricate a fully metallic and large honeycomb cylinder in very light weight. A R&D vacuum shell is being fabricated. Figure 15 shows a picture of a honeycomb panel in the bending process by using 4-point bending technique..

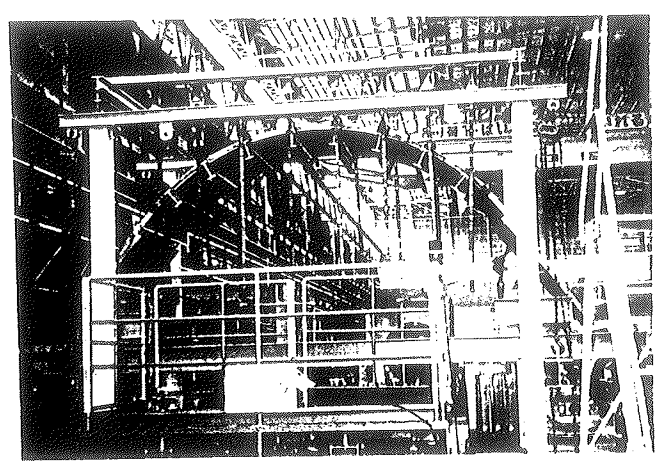

Fig. 15. Picture of four point bending process for brazed honeycomb panel.

VII. SUMMARY

The SDC solenoid design has been made to provide B=2 T with a transparency of 1.2 Xo and 0.25 λ_I in a tracking volume of 3.4 mϕ x 8.8 m. To minimize material in the solenoid, the following technical guide lines have been incorporated into the solenoid design:

- High E/M ratio of 7.5 kJ/kg with high speed quench propagation using pure Al-strip quench propagator to suppress local temperature rise.
- High strength pure aluminum stabilizer (YS> 67 MPa) with RRR=500.
- Honeycomb or iso-grid outer vacuum wall for cryostat.

Based on these guidelines, material corresponding to 0.6 Xo can be saved and the total radiation thickness of 1.2 Xo can be realized. A R&D program is in progress to develop a prototype solenoid magnet with a full diameter and a quarter in length to verify the SDC solenoid design. The prototype magnet will be completed in next year including the cryostat and will be tested to verify the present design and to make feed back to the SDC detector magnet construction. The SDC solenoid is expected to be ready for operation in the SDC detector, 1997.

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